Proceedings of the Research Institute of Atmospherics,
Nagoya University, vol. **24** (1977)

A REAL TIME WHISTLER ANALYZER

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Abstract

A real time analyzer of occurrence number and dispersion of whistlers(abbreviated RTWA) has been developed. In this paper we describe the fundamental principle and the performance of the equipment with reference to the routine base observation. The analyzer will be of great use in studying the detailed temporal and spatial variations of whistler propagations.

1. Introduction

The data of routine observation of whistlers in two minutes every hour have,so far,been analyzed by means of aural counting and sonagraph. This method requires a great deal of labor and analyzing time. Hence,if it is possible to develope an equipment to measure the occurrence number as well as dispersion continuously or in a real time, we shall be able to trace the detailed temporal variation of whistler propagation characteristics. It will be of great use in the study of spatial and temporal variations of whistler ducts(Smith,1961;Helliwell, 1965;Hayakawa and Ohtsu,1973),their formation and decay process,and the behaviours of magnetospheric thermal plasma.

Several workers have made efforts to reduce the labor involved in the aural and sonagraph method. HISSA(Saito and Kuwashima,1970) and Electronic sonagraph(Takahashi and Itoh,1975) have been devised to reduce the analyzing time,but these equipments are not yet enough for a real time analysis.

An attempt to measure the whistler dispersion in a real time was done by Iwai et al.(1971),who tried to discriminate whistlers from surrounding noises by giving,equivalently,a whistler an artificial whistler with its reverse dispersion. However,this method did not operate so effectively because of a poor signal to noise ratio of low-latitude whistlers. Following the Iwai's principle,Fukamachi and Itoh (1974) have been trying a computer-aided analysis.

Another useful system of identifying whistlers is proposed by Eguchi and Ohta(1974),who have made use of frequency modulated nature of whistlers. Using their principle,Okada and Iwai(1976) have developed a system of a real time analyzer for measuring dispersion as well as occurrence number of whistlers. In this paper we describe the outline of the principle and discuss the performance of the equipment based on a three months observation made at Sakushima(geog.lat.34°44'N, long.137°03'E;geomag.lat.24.4°N). Finally we point out some problems involved in this system.

2. The fundamental principle

2-1 Identification of whistlers

As is well-known,whistlers are a kind of frequency-modulated signals whose frequency varies with time according to the relation of $f=D^2/t^2$,where f is the frequency of whistlers,D is the dispersion value and t is the travelling time. Furthermore,the frequency variation of whistlers with time is sufficiently slower than that for atmospherics and tweeks. Using these facts we adopt a frequency discriminator in order to detect whistlers from the noises. Its response characteristic is schematically shown in Fig.1.

A frequency discriminator consists of a band pass limiter(BPL), two band pass filters(BPF),two envelope detecters(Det) and a differential amplifier(Diff.Amp) as is shown in Fig.2. The wide band signal received by the VLF receiver is fed to the BPF's after passing through the BPL. The BPF's output signal is amplified at the three specific frequencies and then enveloped-detected. The signals from Det-1 and

Det-2 are differentially amplified and we get a resultant low frequency signal(V_1). Similarly, the signal V_2 can be obtained.

When the tuning frequencies of three BPF's are selected according to the following relation,

$$T = D\ (f_{k+1}^{-1/2} - f_k^{-1/2})\ ,\ k=1,2$$
$$= \text{const} \cdot D$$

the output signals V_1 and V_2 are found to show quasi-sinusoidal transient variations for the frequency modulated whistler signals as shown in Fig.1. Then it is clear that the time interval between V_1 and V_2 is proportional to the dispersion. (see Fig.1)

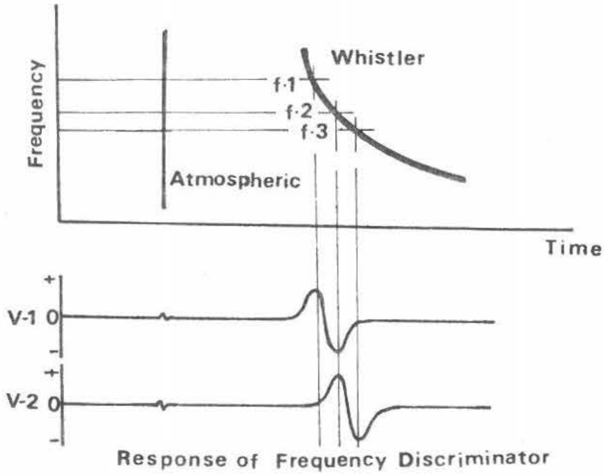

Fig.1 A schematic illustration of quasi-sinusoidal output signal of a whistler from the discriminator. V_1 and V_2 are described in the text and T is the time difference between V_1 and V_2, giving the dispersion value.

In addition to the above relation, another important criterion is needed in choosing the tuning frequencies and the band widths of the BPF's. Namely, from the characteristics of the time response of the BPF to the frequency modulated signals, the band width of the k-th band pass filter must satisfy the following relation,

$$f_k \geq \left| (df/dt)_{f=f_k} \right|^{1/2} = \sqrt{2/D} \cdot f_k^{\ 3/4}$$

and then

$$f_k \geq f_{k+1} + \Delta f_{k+1}\quad ,k=1,2$$

The frequency f_k must be chosen in the band where the energy of whistlers is dominant. And the lowest tuning frequency of the BPF is needed to be set as higher as possible so as to exclude the misdetection of tweeks which are very dispersed around the cut-off frequency. The discriminator which satisfies above conditions becomes very insensitive to impulsive signals such as atmospherics.

Now,we set a threshold value for the output of the discriminator so as to distinguish whistlers from noises because the presence of noises disturbs the output waveform of the discriminator. The threshold value id decided experimintally after examing the response of the discriminator to whistlers and other noises. When the output exceeds the threshold value of V_{th},it is counted as a whistler and this technique is also used to measure the whistler dispersion in a subsequent process.

2-2. Measurement of dispersion

The dispersion can be evaluated from the time difference of the output signal waveforms between V_1 and V_2 by means of a cross-correlation method. The block diagram is shown in Fig.2. The correlator

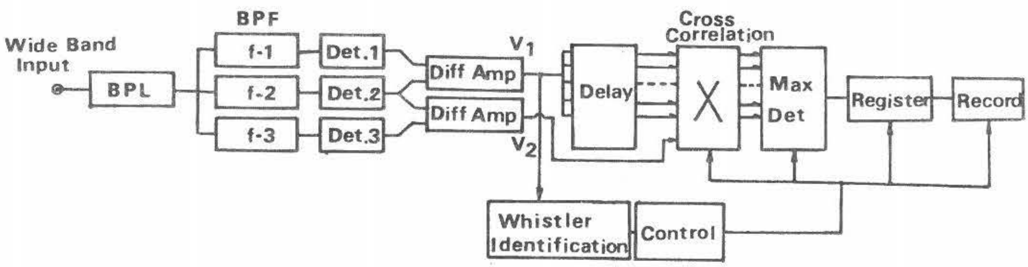

Fig.2 Block diagram of the real time whistler analyzer.

consists of N multi-channels of delay circuit,multiplier and integrator as shown in Fig.2. Now ,we intend to measure the dispersion ranging from D_{min}=15 $sec^{1/2}$ to D_{max}=85 $sec^{1/2}$ in every ΔD=5 $sec^{1/2}$.The signal V_1 is delayed in the j-th channel and cross-correlated with V_2 such that the correlator of the j-th channel gives a maximum coefficient for the whistler dispersion of $D_{min} + (j-1)\cdot\Delta D$.

The circuit of Max.Det. in Fig.2 compares the correlation coefficients from the N channels and finds out the channel of the maximum correlation coefficient which gives the dispersion value of the relevant whistler.

2-3. Parameters of the equipment

The isolated pure-tone whistlers are assumed in the identification of whistlers and the measurement of dispersions in sections 2-1 and 2-2. Detailed consideration should be made for diffused whistlers and multi-flash type ones. A smaller difference between two center frequencies of neighbouring BPF's, such as f_k and f_{k+1} (k=1,2), should be taken to build up the output signals of the discriminators for multi-flash whistlers. On the other hand, this difference must be larger for diffused type ones. So we examined the occurrence distribution of time separation of multi-flash whistlers and occurrence probability of diffuseness at 5 kHz (see Fig.3) using the data obtained at Sakushima during October to November 1975. We define here the multi-flash whistlers to those whose time separation is less than 120 msec. because our equipment can easily detect each component whistler of multi-flash whistlers with longer time separation than the above value, if their dispersion is smaller than 85 $sec^{1/2}$. Fig.4 shows the occurrence probability of various types of whistlers obtained from the observation at Sakushima during October 1975 to March 1976. As a result, the occurrence percentages of isolated-pure, multi-flash and diffused whisters are, on the average, 46 %, 16 % and 15 %, respectively.

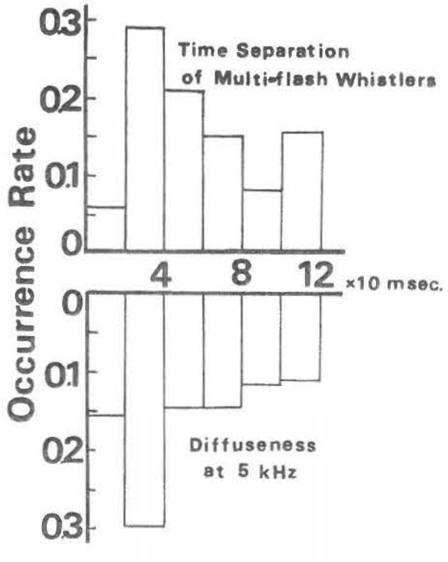

Fig.3 Time separation of multi-flash whistlers (upper panel) and diffuseness defined by the width of the whistler trace on the sonagram at 5 kHz in units of msec. (lower panel) at Sakushima in October to November, 1975.

The equipment was designed to make detection and dispersion measurement of about a half of multi-flash whistlers as well as diffused ones,assuming their occurrence distribution being given by those as shown in Fig.3. So the time resolution of the discriminator was chosen to identify multi-flash whistlers separated by more than 65 msec.. This time separation is sufficient for measuring multi-flash whistlers with dispersion value less than 40 $sec^{1/2}$. But the higher time resolution is needed to detect multi-flash whistlers with dispersion larger than 40 $sec^{1/2}$. Taking into account these values and the requirement mentioned in section 2-1,we chose the BPF tuning frequencies of f_1=5.86,f_2=4.66 and f_3=3.79 kHz. The occurrence rate of various type whistlers often varies in a few minutes. The variation of occurrence rate with type of whistler has an influence on the identification efficiency of the RTWA. This effect will be mentioned later in connection with Figs.7 and 9.

We show an example of the output waveform of the discriminator for a whistler in Fig.5. The figure indicates that the discriminator responds very well to the whistler,but not for atmospherics.

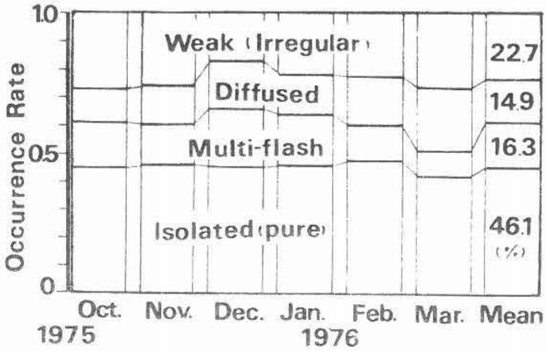

Fig.4 Monthly variation of the occurrence rates of various types of whistlers at Sakushima.

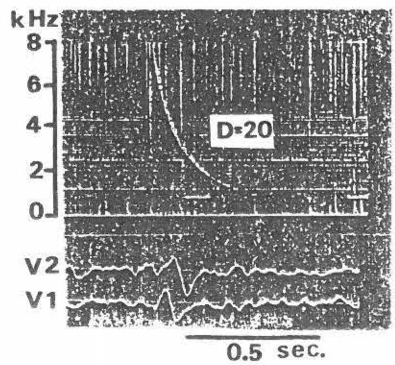

Fig.5 An experimental example of the output waveform of a whistler from the discriminators.

The value of the threshold voltage V_{th} was decided as follows. At first,we introduce three parameters which define the probability of capturing(P_{cap}) as the ratio of whistler numbers detected by the discriminator to the total number of aural counting,the probability of missing(P_{miss}) as the ratio of whistler numbers missed by the discriminator and the rate of error-counting(R_{err}) as the ratio of the number of noise signals counted as whistlers to the total number with aural counting. Fig.6 shows the experimental result on the relationship of these parameters with the threshold value. The figure is statistically obtained from the whistler data at Sakushima during December,1974. The region of R_{err} less than 0.1 corresponds to the range where V_{th} is not smaller than 5.3 volt. In this region, R_{err} decreases very slowly with V_{th} ,while P_{cap} does abruptly. Thus we conveniently took 5.5 volt as the threshold voltage at which R_{err}=0.05 and R_{cap}=0.55.

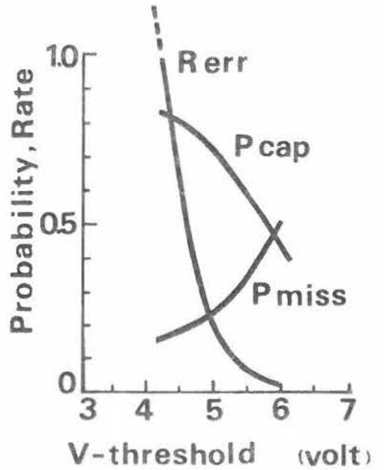

Fig.6 Dependence of the probabilities of capturing and missing(P_{cap}, P_{miss}) and error-counting rate (R_{err}) upon a threshold voltage, setting the output signal for the discriminator.

$P_{cap} + P_{miss} = 1.0$

3. Comparison between the results of the RTWA and the data of routine observation

The upper half of Fig.7 shows the occurrence number obtained for each two minutes by the RTWA at Sakushima during 08h 31m JST on 31 January to 08h 00m JST on 3 February,1976. This result is compared with the occurrence number detected by the routine method(aural) for 50-52 minutes every hour shown in the lower half. It is seen from the figure that the temporal variation of the occurrence number counted by the RTWA has a similar trend with that of the routine data,but the absolute numbers counted by both methods in the same period of 50-52 minutes does not appear to be constant. The variation of the ratio may result from different identification efficiency of the RTWA for various type of whistlers,as discussed in section 2-3.

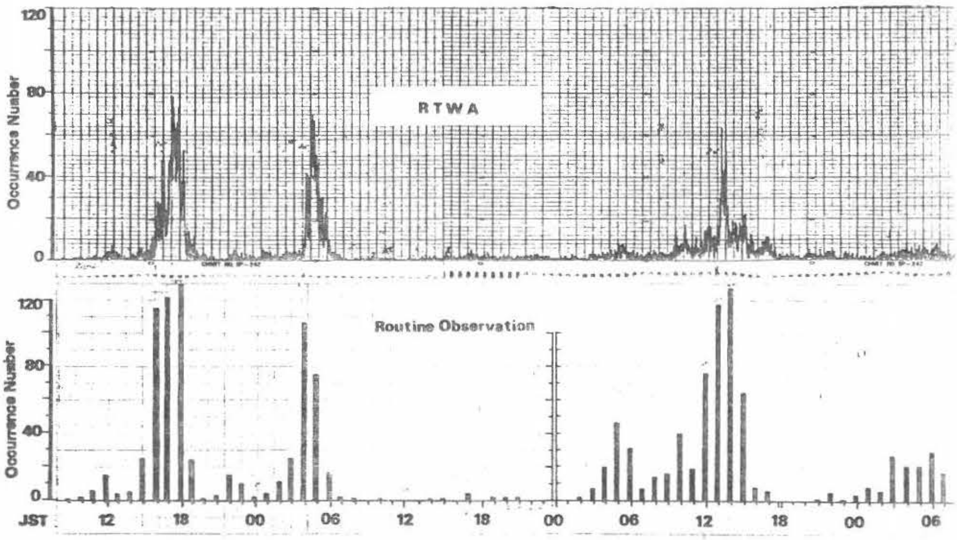

Fig.7 Correlative diagram between the occurrence number obtained by the RTWA and the one by the routine observation at Sakushima during 08h31m JST on 31,January to 08h00m on 3, February,1976.

Fig.8 shows the temporal variations of the dispersion value and the occurrence number obtained with both methods during 21h 00m on 21 March to 20h 00m on 22 March,1976. When a whistler is identified,its dispersion value is measured by the RTWA. If whistlers with different dispersion values are successively received,they are apparently seen as vertical lines in the dispersion data of the RTWA,because the poor time resolution of the pen-oscillograph. And when the occurrence number is zero in a certain period,the voltage level is hold on the horizontal level corresponding to the dispersion value of the preceeding whistler and,as a result,a horizontal line is drawn. it should be noted that there is a comparatively good correspondence between the results by the routine and RTWA methods both for the dispersion and occurrence number.

We examine the efficiency of the RTWA by comparing the occurrence number counted by the RTWA and that by the routine method. We have analyzed 126 cases observed from January,1976 to March,1976. These cases were selected under the criterion that the occurrence number counted with the RTWA exceeds 2 in two minutes,corresponding to the routine observation. Fig.9 represents the relationship between the occurrence numbers obtained by both methods. We can see a good correlation between the occurrence number of the RTWA and routine observations since the correlation coefficient amounts to a significantly high value of 0.87. The straight line in the figure is the regression line obtained by the linear least-square method. The RTWA detects,on the averag,55.7 % of whistlers detected in the routine method. The average value is consistent with the probability of capturing adopted in setting the threshold of the discriminator as discussed in section 2-3.

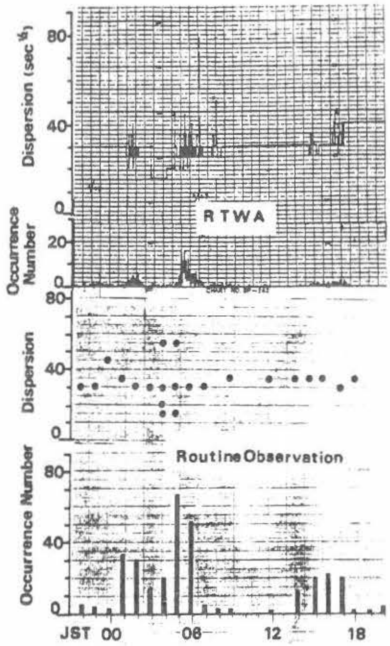

Fig.8 Correlative diagram between the occurrence number and dispersion value based on both methods at Sakushima, 21h 00m on 21 March-20h 00m on 22,March,1976.

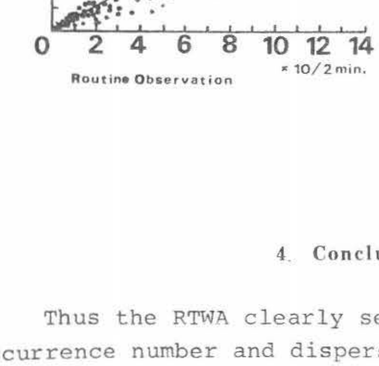

Fig.9 Relationship between the occurrence number by the RTWA and routine observation.

4. Concluding remarks

Thus the RTWA clearly seems to be a useful tool for measuring the occurrence number and dispersion in a real time and especially so for isolated pure-tone whistlers,which are observed mainly at low-latitudes. However it cannot take the place of aural and sonagraph method as the routine method at present,because there are some problems to be solved. They are as follows;

(1) The suppression of error-counting should be firstly done to improve the detection of whistlers. One of the serious causes of the error-counting is attributed to the inhomogeneous distribution of atmospherics energy in the frequency band of the discriminator. The band pass limiter usually acts to homonize the unbalanced frequency dependence of amplitude. But the discriminator often detects unwanted signals whose intensity inhomogeneity is beyond the equalizing ability of the band pass limiter. Another cause is the saturation of the equipment due to the strong atmospherics. In order to solve these problems the erasing circuit against atmospherics including tweeks, the expansion of dynamic range of the VLF receiver and more suitable band pass limiter are considered useful.

(2) Attempts to detect efficiently different types of whistlers are being examined. In order to identify the widely diffused whistlers we firstly convert a diffused whistler signal into a pure-tone signal by a certain circuit and then feed the improved signal to the discriminator.

(3) It should be necessary to identify separately multi-flash whistlers successively received in a short time interval.

After the improvement of the system,the RTWA will take the place of the aural and sonagraph method to analyze the routine data of whistlers in the near future. The RTWA shows the great potential for studying the detailed temporal and spatial variations of whistler propagations in the magnetospheric plasma.

5. Acknowledgement

The authors wish to express their sincere thanks to Dr.T.Ondoh of Radio Research Laboratories and Prof.T.Kamada of their institute for their careful reading and criticism. Thanks are also due to Drs. Y.Tanaka and M.Hayakawa for their valuable discussions during the course of preparation of the present paper. Finally they appreciate the faithful assistance from Messrs.T.Yamaguchi,T.Katoh and Y.Katoh of their laboratory in making the equipment and in the observation.

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